

1. A method for forming a superelastic endodontic instrument comprising the steps of:

providing an instrument blank formed from a wire of superelastic material, wherein the superelastic material of the instrument blank is in an annealed state comprising a phase structure selected from the group consisting of: a rhombohedral phase, a combination of an austenite phase and a martensite phase, a combination of a rhombohedral phase and an austenite phase, a combination of a rhombohedral phase and a martensite phase, and a combination of a rhombohedral phase, an austenite phase and a martensite phase;

while in the annealed state, twisting the instrument blank to a final twisted configuration for the instrument; and

after twisting, heat treating the twisted instrument, followed by rapidly quenching the twisted instrument to a superelastic condition.

2. The method of claim 1 wherein the step of forming the wire is by removing material having a first hardness by a method selected from the group consisting of electrical discharge machining, wire electrical discharge machining, electrical discharge grinding and electrochemical machining, including removing at least about 25% of a diameter of the wire at a point of maximum metal removal, and redepositing at least a portion of the removed material on the instrument blank to form a recast layer having a second hardness of at least about 15% greater than the first hardness.

3. The method of claim 1 wherein the step of forming the wire is by grinding.

4. The method of claim 1 wherein the superelastic material comprises at least about 40 at.% titanium.
5. The method of claim 4 wherein the superelastic material is a nickel-titanium alloy.
6. The method of claim 5 wherein the nickel-titanium alloy further comprises an element selected from the group consisting of: niobium, copper, iron, chromium, cobalt, vanadium, hafnium and palladium.
7. The method of claim 1 wherein the step of twisting the blank is at a temperature less than about 100°C.
8. The method of claim 1 wherein the step of twisting the blank is at ambient temperature.
9. The method of claim 1 wherein the step of heat treating the twisted instrument is at a temperature in the range of about 400-600°C.
10. The method of claim 1 further comprising, after rapidly quenching, heating the twisted instrument to a temperature in the range of about 150-300°C to relieve stress therein.
11. The method of claim 1 wherein the instrument is provided in an annealed state comprising the rhombohedral phase.

12. A method for forming a superelastic endodontic instrument comprising the steps of:

annealing a superelastic material at a temperature in the range of about 250-700°C to an annealed state comprising a phase structure selected from the group consisting of: a rhombohedral phase, a combination of an austenite phase and a martensite phase, a combination of a rhombohedral phase and an austenite phase, a combination of a rhombohedral phase and a martensite phase, and a combination of a rhombohedral phase, an austenite phase and a martensite phase, and cooling the annealed material to ambient temperature;

forming the superelastic material into an instrument blank;

while in the annealed state, twisting the blank at a temperature less than about 100°C to a final twisted configuration for the instrument;

after twisting, heat treating the twisted instrument at a temperature in the range of about 300-800°C, followed by rapidly quenching the twisted instrument to a superelastic condition.

13. The method of claim 12 wherein the step of annealing the superelastic material is at a temperature in the range of about 350-550°C.

14. The method of claim 12 wherein the step of annealing the superelastic material is at a temperature sufficient to provide a phase structure including the rhombohedral phase.

15. The method of claim 12 wherein the step of forming the superelastic material is performed before the step of annealing the superelastic material.

16. The method of claim 15 wherein the step of forming the superelastic material is by removing material having a first hardness by a method selected from the group consisting of electrical discharge machining, wire electrical discharge machining, electrical discharge grinding and electrochemical machining, including removing at
5 least about 25% of a diameter of a starting material at a point of maximum metal removal, and redepositing at least a portion of the removed material on the instrument blank to form a recast layer having a second hardness of at least about 15% greater than the first hardness.
17. The method of claim 15 wherein the step of forming the superelastic material is by grinding.
18. The method of claim 12 wherein the step of forming the superelastic material is performed after the step of annealing the superelastic material.
19. The method of claim 18 wherein the step of forming the superelastic material is by removing material having a first hardness by a method selected from the group consisting of electrical discharge machining, wire electrical discharge machining, electrical discharge grinding and electrochemical machining, including removing at
5 least about 25% of a diameter of a starting material at a point of maximum metal removal, and redepositing at least a portion of the removed material on the instrument blank to form a recast layer having a second hardness of at least about 15% greater than the first hardness.

20. The method of claim 18 wherein the step of forming the superelastic material is by grinding.
21. The method of claim 12 wherein the step of twisting the blank is at ambient temperature.
22. The method of claim 12 wherein the step of heat treating the twisted instrument is at a temperature in the range of about 400-600°C.
23. The method of claim 12 further comprising, after rapidly quenching, heating the twisted instrument to a temperature in the range of about 150-300°C to relieve stress therein.
24. The method of claim 23 wherein the twisted instrument is heated for a period of about 2-6 hours.
25. The method of claim 12 wherein the superelastic material comprises at least about 40 at.% titanium.
26. The method of claim 25 wherein the superelastic material is a nickel-titanium alloy.
27. The method of claim 26 wherein the nickel-titanium alloy further comprises an element selected from the group consisting of: niobium, copper, iron, chromium, cobalt, vanadium, hafnium and palladium.

28. A method for forming a superelastic endodontic instrument comprising the steps of:

annealing a nickel-titanium alloy at a temperature in the range of about 250-700°C to an annealed state comprising a phase structure selected from the group consisting of: a rhombohedral phase, a combination of an austenite phase and a martensite phase, a combination of a rhombohedral phase and an austenite phase, a combination of a rhombohedral phase and a martensite phase, and a combination of a rhombohedral phase, an austenite phase and a martensite phase, and cooling the annealed alloy to ambient temperature;

forming the annealed alloy into an instrument blank;

twisting the instrument blank at ambient temperature to a final twisted configuration for the instrument;

heat treating the twisted instrument at a temperature in the range of about 300-800°C, followed by rapidly quenching the twisted instrument to a superelastic condition.

29. The method of claim 28 wherein the step of annealing the nickel-titanium alloy is at a temperature in the range of about 350-550°C.

30. The method of claim 28 wherein the step of annealing the nickel-titanium alloy is at a temperature sufficient to provide a phase structure including the rhombohedral phase.

31. The method of claim 28 wherein the step of forming the alloy is by removing material having a first hardness by a method selected from the group consisting of electrical discharge machining, wire electrical discharge machining, electrical discharge grinding and electrochemical machining, including removing at least about 25% of a diameter of a starting material at a point of maximum metal removal, and redepositing at least a portion of the removed material on the instrument blank to form a recast layer having a second hardness of at least about 15% greater than the first hardness.
32. The method of claim 28 wherein the step of forming the alloy is by grinding.
33. The method of claim 28 wherein the step of heat treating the twisted instrument is at a temperature in the range of about 400-600°C.
34. The method of claim 28 further comprising, after rapidly quenching, heating the twisted instrument to a temperature in the range of about 150-300°C to relieve stress therein.
35. The method of claim 34 wherein the twisted instrument is heated for a period of about 2-6 hours.
36. The method of claim 28 wherein the nickel-titanium alloy comprises at least about 40 at.% titanium.

37. The method of claim 36 wherein the nickel-titanium alloy further comprises an element selected from the group consisting of: niobium, copper, iron, chromium, cobalt, vanadium, hafnium and palladium.

38. A method for forming a superelastic endodontic instrument comprising the steps of:

forming an instrument blank from a nickel-titanium alloy wire;

annealing the instrument blank at a temperature in the range of about

5 250-700°C to an annealed state comprising a phase structure selected from the group consisting of: a rhombohedral phase, a combination of an austenite phase and a martensite phase, a combination of a rhombohedral phase and an austenite phase, a combination of a rhombohedral phase and a martensite phase, and a combination of a rhombohedral phase, an austenite phase and a martensite phase, and cooling the
10 annealed instrument blank to ambient temperature;

twisting the annealed instrument blank at ambient temperature to a final twisted configuration for the instrument;

heat treating the twisted instrument at a temperature in the range of about 300-800°C, followed by rapidly quenching the twisted instrument to a superelastic
15 condition.

39. The method of claim 38 wherein the step of annealing the instrument blank is at a temperature in the range of about 350-550°C.

40. The method of claim 38 wherein the step of annealing the instrument blank is at a temperature sufficient to provide a phase structure including the rhombohedral phase.

41. The method of claim 38 wherein the step of forming the alloy wire is by removing material having a first hardness by a method selected from the group consisting of electrical discharge machining, wire electrical discharge machining, electrical discharge grinding and electrochemical machining, including removing at least about 25% of a diameter of the alloy wire at a point of maximum metal removal, and redepositing at least a portion of the removed material on the instrument blank to form a recast layer having a second hardness of at least about 15% greater than the first hardness.
42. The method of claim 38 wherein the step of forming the alloy wire is by grinding.
43. The method of claim 38 wherein the step of heat treating the twisted instrument is at a temperature in the range of about 400-600°C.
44. The method of claim 38 further comprising, after rapidly quenching, heating the twisted instrument to a temperature in the range of about 150-300°C to relieve stress therein.
45. The method of claim 44 wherein the twisted instrument is heated for a period of about 2-6 hours.
46. The method of claim 38 wherein the nickel-titanium alloy comprises at least about 40 at.% titanium.

47. The method of claim 46 wherein the nickel-titanium alloy further comprises an element selected from the group consisting of: niobium, copper, iron, chromium, cobalt, vanadium, hafnium and palladium.

48. A method for forming an endodontic instrument comprising:
removing material having a first hardness from an instrument blank by a
method selected from the group consisting of electrical discharge machining, wire
electrical discharge machining, electrical discharge grinding and electrochemical
5 machining to form a plurality of flutes having a non-directional surface finish,
wherein at least about 25% of the diameter of the instrument blank is
removed at a point of maximum metal removal, and
redepositing at least a portion of the removed material on the flutes being
formed to form a recast layer having a second hardness of at least about 15% greater
10 than the first hardness.
49. The method of claim 48 further comprising forming the instrument blank
from a wire of the material to a pre-determined cross-sectional shape by a method
selected from the group consisting of electrical discharge machining, wire electrical
discharge machining, electrical discharge grinding and electrochemical machining.
50. The method of claim 48 further comprising twisting the instrument blank
having the plurality of flutes to form a plurality of helical flutes.
51. The method of claim 48 wherein the material is a superelastic material.
52. The method of claim 51 wherein the superelastic material is a nickel-
titanium alloy.

53. The method of claim 52 wherein the nickel-titanium alloy comprises at least about 40 at.% titanium.

54. The method of claim 53 wherein the nickel-titanium alloy further comprises an element selected from the group consisting of: niobium, copper, iron, chromium, cobalt, vanadium, hafnium and palladium.

55. The method of claim 48 wherein the material is stainless steel.

56. The method of claim 48 wherein the material is a steel alloy.

57. The method of claim 48 wherein removing material to form the plurality of flutes includes:

(a) rotating the instrument blank about it's center longitudinal axis while advancing the instrument blank past an electrode without direct contact to remove the material thereby forming a first of the plurality of flutes extending helically around the center longitudinal axis of the instrument blank, then

(b) rotatably indexing the instrument blank about the center longitudinal axis not more than 180 degrees and repeating step (a) thereby forming a second of the plurality of flutes extending helically around the center longitudinal axis of the instrument blank.

58. The method of claim 57 further comprising:

(c) repeating step (b) a desired number of times to form a desired number of flutes.

59. The method of claim 57 comprising holding the electrode stationary while advancing the instrument past the electrode.

60. The method of claim 57 comprising rotating the electrode while advancing the instrument past the electrode.

61. The method of claim 57 wherein the instrument blank is advanced past the electrode at a rate of between about .025 and about 4 inches per minute.

62. The method of claim 48 wherein removing material to form the plurality of flutes includes:

(a) holding the instrument blank stationary while advancing an electrode past the instrument blank without direct contact to remove the material thereby forming
5 a first of the plurality of flutes extending non-helically along the center longitudinal axis of the instrument blank, then

(b) rotatably indexing the instrument blank about the center longitudinal axis not more than 180 degrees and repeating step (a) thereby forming a second of the plurality of flutes extending in axial alignment with the first of the plurality of flutes.

63. The method of claim 62 further comprising:

(c) repeating step (b) a desired number of times to form a desired number of flutes.

64. The method of claim 62 wherein the electrode is advanced past the instrument blank at a rate of between about 0.25 and about 4 inches per minute.

65. The method of claim 48 further comprising providing a surface pattern on the electrode whereby a reverse image of the surface pattern is produced on the instrument blank as the material is being removed.

66. A method for forming an endodontic instrument comprising the steps of:
forming a wire into an instrument blank of material initially having a first hardness;

forming a first helical flute in the instrument blank by a method selected
5 from the group consisting of electrical discharge machining, wire electrical discharge machining, electrical discharge grinding and electrochemical machining, including rotating the instrument blank about it's center longitudinal axis while advancing the instrument blank axially past an electrode without direct contact with the instrument blank to remove material therefrom and thereby form the first helical flute therein,
10 wherein at least about 25% of the diameter of the instrument blank is removed at a point of maximum metal removal, and to redeposit at least a portion of the removed material on the flute being formed to form a recast layer having a non-directional surface finish and a second hardness at least about 15% greater than the first hardness; and
rotatably indexing the instrument blank about the center longitudinal axis
15 not more than 180 degrees and repeating the forming step to form a second helical flute having a non-directional surface finish and the second hardness at least about 15% greater than the first hardness.

67. The method of claim 66 further comprising repeating the indexing step a desired number of times to form a desired number of helical flutes.

68. The method of claim 66 wherein the instrument blank is formed from a wire of the material to a pre-determined cross-sectional shape by a method selected from the group consisting of electrical discharge machining, wire electrical discharge machining, electrical discharge grinding and electrochemical machining.

69. The method of claim 66 wherein the material is a superelastic material.
70. The method of claim 69 wherein the superelastic material is a nickel-titanium alloy.
71. The method of claim 70 wherein the nickel-titanium alloy comprises at least about 40 at.% titanium.
72. The method of claim 71 wherein the nickel-titanium alloy further comprises an element selected from the group consisting of: niobium, copper, iron, chromium, cobalt, vanadium, hafnium and palladium.
73. The method of claim 66 wherein the material is stainless steel.
74. The method of claim 66 wherein the material is a steel alloy.
75. The method of claim 66 comprising holding the electrode stationary while advancing the instrument past the electrode.
76. The method of claim 66 comprising rotating the electrode while advancing the instrument past the electrode.
77. The method of claim 66 wherein the instrument blank is advanced past the electrode at a rate of between about 0.25 and about 4 inches per minute.

78. The method of claim 66 further comprising providing a surface pattern on the electrode whereby a reverse image of the surface pattern is produced on the instrument blank as the material is being removed.

79. A method for forming an endodontic instrument comprising the steps of:
forming a wire into an instrument blank of material initially having a first hardness;

forming a first non-helical flute in the instrument blank by a method
5 selected from the group consisting of electrical discharge machining, wire electrical discharge machining, electrical discharge grinding and electrochemical machining, including holding the instrument blank stationary about it's center longitudinal axis while advancing an electrode axially past the instrument blank without direct contact with the instrument blank to remove material therefrom and thereby form the first non-
10 helical flute therein, wherein at least about 25% of the diameter of the instrument blank is removed at a point of maximum metal removal, and to redeposit at least a portion of the removed material on the flute being formed to form a recast layer having a non-directional surface finish and a second hardness at least about 15% greater than the first hardness; and
15 rotatably indexing the instrument blank about the center longitudinal axis not more than 180 degrees and repeating the forming step to form a second non-helical flute extending in axial alignment with the first non-helical flute, the second non-helical flute having a non-directional surface finish and a second hardness at least about 15% greater than the first hardness.

80. The method of claim 79 further comprising repeating the indexing step a desired number of times to form a desired number of non-helical flutes.

81. The method of claim 79 wherein the instrument blank is formed from a wire of the material to a pre-determined cross-sectional shape by a method selected from the group consisting of electrical discharge machining, wire electrical discharge machining, electrical discharge grinding and electrochemical machining.
82. The method of claim 79 wherein the material is a superelastic material.
83. The method of claim 82 wherein the superelastic material is a nickel-titanium alloy.
84. The method of claim 83 wherein the nickel-titanium alloy comprises at least about 40 at.% titanium.
85. The method of claim 84 wherein the nickel-titanium alloy further comprises niobium.
86. The method of claim 79 wherein the material is stainless steel.
87. The method of claim 79 wherein the material is a steel alloy.
88. The method of claim 79 wherein the electrode is advanced past the instrument blank at a rate of between about 0.25 and about 4 inches per minute.

89. The method of claim 79 further comprising providing a surface pattern on the electrode whereby a reverse image of the surface pattern is produced on the instrument blank as the material is being removed.